ApJ Letters, in press
Preprint typeset using LaTeX style emulateapj v. 14/09/00

CLUSTERING PROPERTIES OF GALAXIES AT $Z \sim 4$ IN THE SUBARU/XMM DEEP SURVEY FIELD [1]

Masami Ouchi [2], Kazuhiro Shimasaku [2,3], Sadanori Okamura [2,3],
Mamoru Doi [4], Hisanori Furusawa [2], Masaru Hamabe [5], Masahiko Kimura [6],
Yutaka Komiyama [7], Masayuki Miyazaki [2], Satoshi Miyazaki [8], Fumiaki Nakata [2],
Maki Sekiguchi [6], Masafumi Yagi [8], and Naoki Yasuda [8]
ouchi@astron.s.u-tokyo.ac.jp

ApJ Letters, in press

ABSTRACT

We study the clustering properties of about 1200 $z \sim 4$ Lyman Break Galaxy (LBG) candidates with $i' < 26$ which are selected by color from deep BRi' imaging data of a 618 arcmin^2 area in the Subaru/XMM-Newton Deep Field taken with Subaru Prime Focus Camera. The contamination and completeness of our LBG sample are evaluated, on the basis of the Hubble Deep Field North (HDFN) objects, to be 17% and 45%, respectively. We derive the angular correlation function over $\theta = 2'' - 1000''$, and find that it is fitted fairly well by a power law, $\omega(\theta) = A_\omega \theta^{-0.8}$, with $A_\omega = 0.71 \pm 0.26$. We then calculate the correlation length r_0 (in comoving units) of the two-point spatial correlation function $\xi(r) = (r/r_0)^{-1.8}$ from A_ω using the redshift distribution of LBGs derived from the HDFN, and find $r_0 = 2.7^{+0.5}_{-0.6}\, h^{-1}$ Mpc in a Λ-dominated universe ($\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$). This is twice larger than the correlation length of the dark matter at $z \simeq 4$ predicted from an analytic model by Peacock & Dodds but about twice smaller than that of bright galaxies predicted by a semi-analytic model of Baugh et al. We find an excess of $\omega(\theta)$ on small scales ($\theta \lesssim 5''$) departing from the power law fit over 3 σ significance levels. Interpreting this as due to galaxy mergers, we estimate the fraction of galaxies undergoing mergers in our LBG sample to be 3.0 ± 0.9%, which is significantly smaller than those of galaxies at intermediate redshifts.

Subject headings: cosmology: observations — cosmology: early universe — cosmology: large-scale structure of universe — galaxies: high-redshift — galaxies: evolution

1. INTRODUCTION

Studies of clustering properties of galaxies at high redshifts are essential for understanding galaxy formation and its relationship to structure formation. The most efficient way to select high redshift ($z > 2.5$) galaxies is the Lyman break technique. High redshift galaxies are isolated in a two-color plane using their UV continuum properties, and galaxies selected in this way are called Lyman break galaxies (LBGs). Giavalisco et al. (1998) studied clustering properties of LBGs on the basis of a large sample for bright ($R < 25.5$) LBGs lying around $z = 3$ selected by U_nGR colors. They found that the spatial distribution of $z = 3$ LBGs is strongly biased relative to the expectations for the dark matter in Cold Dark Matter models with a linear bias of 4.5 predicted for an Einstein-de Sitter cosmology (see also Adelberger et al. 1998). In a subsequent paper, Giavalisco & Dickinson (2001; GD01) found the clustering amplitude of $z \sim 3$ LBGs to depend on their rest-frame ultraviolet luminosity, with fainter galaxies being less strongly clustered. Arnouts et al. (1999) measured the correlation length of faint galaxies in the Hubble Deep Field North (HDFN) over the redshift range $0 < z < 4$, though errors in their measurements are large due to small statistics.

The aim of this paper is to extend the studies on galaxy clustering to $z \sim 4$ LBGs using a large sample of about 1200 LBG candidates identified by the two color ($B - R$ vs $R - i'$) selection technique. This is the largest sample of $z \sim 4$ LBGs in a contiguous area obtained to date, and thus enables detailed studies of clustering properties of galaxies at the highest redshift. Throughout this paper, magnitudes are in the AB system.

2. OBSERVATIONS AND DATA REDUCTION

Deep and wide-field B-,V-,R- and i'-band imaging data of a central $30' \times 24'$ area in the Subaru/XMM-Newton Deep Survey Field ($2^h18^m00^s$,$-5°12'00''$[J2000]) were taken with Subaru Prime Focus Camera (Suprime-Cam; Miyazaki et al. 1998) during the commissioning observing runs on November 24-27, 2000. The present work is based on the B, R, and i' data. The individual CCD data were reduced and combined using IRAF and the mosaic-CCD data reduction software developed by us

[1] Based on data collected at Subaru Telescope, which is operated by the National Astronomical Observatory of Japan.

[2] Department of Astronomy, School of Science, University of Tokyo, Tokyo 113-0033, Japan
[3] Research center for the Early Universe, School of Science, University of Tokyo, Tokyo 113-0033, Japan
[4] Institute of Astronomy, School of Science, University of Tokyo, Mitaka, Tokyo 181-0015, Japan
[5] Department of Mathematical and Physical Sciences, Faculty of Science, Japan Women's University, Tokyo 112-8681, Japan
[6] Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582
[7] Subaru Telescope, National Astronomical Observatory, 650 N.A'ohoku Place, Hilo, HI 96720, USA
[8] National Astronomical Observatory, Mitaka, Tokyo 181-8588, Japan

(Yagi 1998). The combined images for individual bands were aligned and smoothed with Gaussian kernels to match their seeing sizes. The final images cover a contiguous 618 arcmin^2 area with a PSF FWHM of $0.''98$. The net exposure times of the final images are 177, 58, and 45 minutes for B, R, and i', respectively. The limiting magnitudes are $B = 27.6$, $R = 26.5$, and $i' = 26.2$ for a 3σ detection on a $2''$ diameter aperture. Source detection and photometry are performed using SExtractor version 2.1.6 (Bertin & Arnouts 1996). The i'-band frame is chosen to detect objects, and we limit the object catalog to $i' \leq 26$, in order to provide a reasonable level of photometric completeness.

3. SELECTION OF $z \sim 4$ LYMAN BREAK GALAXIES

Our catalog contains 42,557 objects with $i' \leq 26.0$ in total. On the basis of expectations from GISSEL96 (Bruzual & Charlot 1993) population synthesis models [9] with dust attenuation of $E(B-V) = 0 - 0.5$ assuming Calzetti 's (1997) extinction law, we define the photometric selection criteria for galaxies at $z \sim 4$ as

$$B - R > 2.1, R - i' < 0.5, B - R > 5.4(R - i') + 0.9 \quad (1)$$

We estimate from the models that the expected redshift distribution of galaxies satisfying eq. (1) is $z = 3.8 \pm 0.5$ (Ouchi et al. 2001).

There are a total of 1,192 objects which meet the criteria. Figure 1 shows the number counts of the objects, without correction for incompleteness of detections, against i' (filled circles). It is found that our counts are consistent with those given in Steidel et al. (1999), who selected $z \sim 4$ LBGs using GRI color, and that the faint end of our counts matches the counts derived from the HDFN. For the following analyses, we define three LBG samples; (1) the whole sample containing 1,192 objects, (2) the sample for bright ($i' < 25.5$) objects, and (3) the sample for faint ($25.5 < i' < 26$) objects.

We have estimated the contamination and completeness of our LBG sample by Monte Carlo simulations, generating artificial galaxies using the HDFN objects for which magnitudes, colors, and photometric redshifts are given in Fernández-Soto, Lanzetta, & Yahil (1999), and distributing them on our original images (Ouchi et al. 2001). The contamination is defined, for the detected simulated objects, as the ratio of low redshift ($z < 3.3$) objects meeting eq.(1), to all objects satisfying eq.(1). The completeness is defined as the ratio of $i' < 26$ simulated objects passing our detection threshold *and* satisfying eq.(1), to all (detected + undetected) $i' < 26$ simulated objects. We find from the simulations that the completeness is 45%, 51%, and 40% for the whole, bright, and faint samples, respectively. Similarly, the contamination is 17%, 19%, and 14%, respectively. Note that the completeness defined here is a combination of the detection completeness and the completeness of color selection. Our color criteria effectively sample HDFN galaxies at $3.3 < z < 4.3$ with a selection completeness of 89%. Namely, 89% of $z \simeq 4$ galaxies pass eq.(1) once they are detected. We adopt for the redshift distribution $N(z)$ of LBGs in our sample the one derived from the simulations taking account of the contamination and completeness.

4. ANGULAR CORRELATION FUNCTION

Figure 2 shows the sky distribution of $z \sim 4$ LBGs in our sample. We find in this figure somewhat an inhomogeneous distribution of LBGs, especially for bright ($i' < 24.5$) ones. This is not due to the inhomogeneity of detection completeness over the image, because the Monte Carlo simulations show that differences in detection completeness among small ($1.'7 \times 1.'7$) areas in the image are less than 10%, and that the detection completeness does not correlate with the distribution of LBGs.

We derive the angular two-point correlation function, $\omega(\theta)$, using the estimator defined by Landy & Szalay (1993), $\omega_{obs}(\theta) = [DD(\theta) - 2DR(\theta) + RR(\theta)]/RR(\theta)$, where $DD(\theta)$, $DR(\theta)$, and $RR(\theta)$ are numbers of galaxy-galaxy, galaxy-random, and random-random pairs normalized by the total number of pairs in each of the three samples. The random sample is composed of 200,000 sources with the same geometrical constraints of the data sample. The formal error [10] in $\omega(\theta)$ is assigned by $\sigma_\omega = \sqrt{[1 + \omega_{obs}(\theta)]/RR}$. The real correlation function $\omega(\theta)$ is offset by the integral constant (IC: Groth & Peebles 1977); $\omega(\theta) = \omega_{obs}(\theta) + IC$,where IC of the whole sample is calculated to be 0.0045.

The resulting angular correlation function for the whole sample is shown in Figure 3 after the application of IC. We fit a power law, $\omega(\theta) = A_\omega \theta^{-\beta}$, to the data points, and find the slope $\beta = 0.6^{+0.6}_{-0.4}$, which is consistent with those for nearby galaxies, $\beta = 0.7 - 0.8$, though the errors in our estimate are large. The best fit values of A_ω for $\beta \equiv 0.8$ are summarized in Table 1.

The two-point angular correlation function is related to the spatial correlation function $\xi(r) = (r/r_0)^{-\gamma}$ by an integral equation, the Limber transformation (Peebles 1980;Efstathiou et al. 1991).

$$A_\omega = C r_0^\gamma \int_0^\infty F(z) D_\theta^{1-\gamma}(z) N(z)^2 g(z) dz \left[\int_0^\infty N(z) dz\right]^{-2} \quad (2)$$

where $F(z)$ [11] describes the redshift dependence of $\xi(r)$, $D_\theta(z)$is the angular diameter distance, $g(z) = \frac{H_0}{c}[(1+z)^2(1+\Omega_m z + \Omega_\Lambda((1+z)^{-2}-1))^{1/2}]$, and C is a numerical constant $C = \sqrt{\pi}\frac{\Gamma[(\gamma-1)/2]}{\Gamma(\gamma/2)}$. The slope β is related by $\beta = \gamma - 1$. The Limber transformation requires the redshift distribution $N(z)$ of LBGs (see §3). We adopt the one derived from the simulations based on the HDFN galaxies (see §3). The obtained values of r_0 are presented in Table 1 for three cosmologies, $(\Omega_m, \Omega_\Lambda) = (0.3, 0.7), (0.3, 0)$,and $(1, 0)$. Those correlation lengths correspond to projected angular scales of $100'' - 110''$ at $z = 3.8$. These scales fall just outside of the range where the power-law fitting is excellent ($10'' < \theta < 100''$), implying that r_0 is reliably measured from the fit. Varying $N(z)$ in a reasonable range

[9] The model parameters are chosen to match the observed colors of $z = 3$ galaxies: Salpeter IMF, $Z_{metal} = 0.2 Z_\odot$, and an age of 10 Myr for an instantanious burst (Sawicki & Yee 1998).

[10] The formal error does not include sample variance, which is caused from field-to-field variations.

[11] Assuming that the clustering pattern is fixed in comoving coordinates in the redshift range of our sample, we take the functional form, $F(z) = (1+z)/(1+3.8)^{-(3+\epsilon)}$, where $\epsilon = -1.2$. The effect of the change in ϵ over $0 < \epsilon < -3$ on r_0 is, however, very small.

changes the results only slightly; for example, a tophat distribution over $3.3 < z < 4.3$ returns 8% larger values, and adopting a narrower distribution, $3.4 < z < 4.2$, decreases r_0 by 11%. The random contaminant objects dilute the amplitudes of angular correlation function, A_ω, by a factor up to $(1-f)^2$, where f is the contamination (see §3). The contamination correction increases r_0 by about 20% at most. The effect of field-to-field variations in our sample is probably modest, since our sample probes a large comoving volume, $36 \times 36 \times 520 = 6.7 \times 10^5 h^{-3}$ Mpc^3 for $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$ cosmology. Observations of other fields and analyses of N-body simulations for structure formation will be useful for evaluation of the effect of field variation.

5. DISCUSSION & CONCLUSIONS

Figure 4 shows the observed correlation length r_0 (in comoving units) of galaxies at $\langle z \rangle = 3.8$ in our sample, together with those at various redshifts between $z = 0$ and 3. Two data points at $z = 3$ are the measurements by GD01 for bright ($R < 25.5$) LBGs and faint ($R < 27$) LBGs. It is found that the r_0 for our whole sample is only slightly smaller than that for GD01's bright LBGs at $z = 3$ (The difference in the mean brightness in our three samples is less than 1 mag, and the absolute magnitudes probed by our samples correspond roughly to those probed by GD01's bright sample). This suggests that the clustering amplitude does not change significantly from $z = 3$ to 3.8, with a possible decrease within $\sim$ 50%. GD01 found strong luminosity dependence of r_0 for $z = 3$ LBGs as shown in Figure 4. Our sample does not contain as faint LBGs as they studied, but we also find possible dependence on luminosity in our sample, with fainter LBGs having a smaller r_0. Arnouts et al. (1999) obtained a large value $r_0 = (4.28 \pm 1.69)h^{-1}$ Mpc for $z \sim 4$ galaxies in the HDFN. This is the opposite sense since the galaxies in the HDFN are fainter than those in our sample. However, the number of galaxies they used is only 35.

The r_0 values of LBGs at $z = 3 - 4$ are about half that of the nearby galaxies. The dotted and solid lines in Figure 4 present, respectively, the evolution of r_0 for the dark matter predicted by an analytic model and 'galaxies' of $R < 25.5$ predicted by a semi-analytic model for galaxy formation in a cold dark matter universe with $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and $\sigma_8 = 0.94$ (Baugh et al. 1999). For the reader's guide, we also show by the dashed line the r_0 of the dark matter predicted by linear theory normalized to $r_0(0) = 5.3h^{-1}$ Mpc. The r_0 of the observed LBGs at $z = 3.8$ is found to be 2.9 times larger than that for the dark matter given by Baugh et al. (1999) (In practice, Baugh et al. adopted for the dark matter correlation function the analytic model of Peacock & Dodds 1996.) Note that if one compares predicted correlation lengths for galaxies with observations, predictions should be made based on selection criteria of galaxies which are similar to those adopted in the observations. If we interpret this as biasing of galaxy distribution, which is expressed as $\xi_{gal}(r) = b^2 \xi_{matter}(r)$, we obtain a linear bias $b \sim 2.6$, which is similar to that found by GD01 for bright $z = 3$ LBGs. On the other hand, the semi-analytic model predicts much stronger clustering for galaxies (Similar predictions are made by, eg, Kauffmann et al. 1999 and Yoshikawa et al. 2001). The predicted value at $z = 3.8$ is twice as large as observed in this study. Further discussion requires a detailed comparison of galaxy properties, including selection criteria, between their simulated galaxies and the LBGs in our sample.

In Figure 3, we find an excess [12] of $\omega(\theta)$ at small scales ($\theta \lesssim 5''$), over 3 σ significance levels, relative to the best fit power law. This may be caused from various effects, for example, galaxy-galaxy mergers, two galaxies within a common dark matter halo, and/or field variance. If we interpret this as galaxy-galaxy mergers of those $i' < 26$ LBGs, which are classified as bright LBGs with $L_{1700\mathring{A}} \gtrsim L^*_{1700\mathring{A}}$ (Ouchi et al. 2001), we calculate, following Roche & Eales (1999), the fraction of galaxies undergoing mergers as $f_{pair} = 3.0 \pm 0.9\%$ from the observed and expected numbers of galaxy pairs with a separation of $1.''5 < \theta < 4''$ (projected physical separation corresponds to 7.5 to 20 h^{-1}kpc at $z = 3.8$), where the expected number is calculated from an integration over $1.''5 < \theta < 4''$ of the best fit power law derived for the data at $\theta > 4''$. This f_{pair} value is significantly smaller than those for intermediate-redshift ($z \sim 0.3$) galaxies whose f_{pair} at $\lesssim 20\ h^{-1}$kpc is $5 - 15\%$ (Carlberg, Pritchet, & Infante 1994; Infante, de Mello, & Menanteau 1996; Roche & Eales 1999). This may imply that merger rates for massive galaxies are lower at $z \sim 4$ than at present, if we assume that bright LBGs are massive. However, i'-band magnitudes (rest-frame UV for $z \sim$ 4LBGs) are sensitive to on-going star-formation activities, and those luminosities reflect intensity of current star-formation. Observing those LBGs in near-IR bands and estimating their mass are needed to address this issue.

We thank the anonymous referee for detailed comments which improved this manuscript. We would like to thank the Subaru Telescope staff for their invaluable help in commisioning the Suprime-Cam that makes these difficult observations possible. M. Ouchi, H. Furusawa, and F. Nakata acknowledge support from the Japan Society for the Promotion of Science (JSPS) through JSPS Research Fellowships for Young Scientists.

REFERENCES

Adelberger, K. L., Steidel, C. C., Giavalisco, M., Dickinson, M., Pettini, M., & Kellogg, M. 1998, ApJ, 505, 18
Arnouts, S., Cristiani, S., Moscardini, L., Matarrese, S., Lucchin, F., Fontana, A., & Giallongo, E. 1999, MNRAS, 310, 540
Baugh, C. M., Benson, A. J., Cole, S., Frenk, C. S., & Lacey, C. G. 1999, MNRAS, 305, L21
Bertin, E. & Arnouts, S. 1996, A&AS, 117, 393
Brunner, R. J., Szalay, A. S., & Connolly, A. J. 2000, ApJ, 541, 527
Bruzual A., G. & Charlot, S. 1993, ApJ, 405, 538
Calzetti, D. 1997, AJ, 113, 162
Carlberg, R. G., Pritchet, C. J., & Infante, L. 1994, ApJ, 435, 540
Carlberg, R. G., Yee, H. K. C., Morris, S. L., Lin, H., Hall, P. B., Patton, D., Sawicki, M., & Shepherd, C. W. 2000, ApJ, 542, 57

[12] A visual inspection find that all the galaxies contributing to the excess are real; no artificial object such as haloes of bright stars is found to be included in them.

Efstathiou, G., Bernstein, G., Tyson, J. A., Katz, N., & Guhathakurta, P. 1991, ApJ, 380, L47
Fernández-Soto, A. and Lanzetta, K. M. and Yahil, A. 1999, ApJ, 513, 34
Giavalisco, M., Steidel, C. C., Adelberger, K. L., Dickinson, M. E., Pettini, M., & Kellogg, M. 1998, ApJ, 503, 543
Giavalisco, M. & Dickinson, M. 2001, ApJ, 550, 177 (GD01)
Groth, E. J. & Peebles, P. J. E. 1977, ApJ, 217, 385
Infante, L., de Mello, D., & Menanteau, F. 1996, ApJ, 469, L85
Kauffmann, G., Colberg, J. ;. M., Diaferio, A., & White, S. D. M. 1999, MNRAS, 307, 529
Landy, S. D. & Szalay, A. S. 1993, ApJ, 412, 64
Loveday, J., Maddox, S. J., Efstathiou, G., & Peterson, B. A. 1995, ApJ, 442, 457
Madau, P., Ferguson, H. C., Dickinson, M. E., Giavalisco, M., Steidel, C. C., & Fruchter, A. 1996, MNRAS, 283, 1388
Miyazaki, S., Sekiguchi, M., Imi, K., Okada, N., Nakata, F. & Komiyama, Y. 1998, SPIE, 3355, 363
Ouchi, M., Shimasaku, K., Okamura, S., Doi,, M., Miyazaki, M., Komiyama, Y., Yagi, M.,Nakata, F., Furusawa, H., Miyazaki, M. 2001, in preparation
Peacock, J. A. & Dodds, S. J. 1996, MNRAS, 280, L19
Peebles, P. J. E. 1980, The Large-Scale Structure of the Universe (Princeton: Princeton Univ. Press)
Roche, N. & Eales, S. A. 1999, MNRAS, 307, 703
Sawicki, M. & Yee, H. K. C. 1998, AJ, 115, 1329
Steidel, C. C., Giavalisco, M., Pettini, M., Dickinson, M., & Adelberger, K. L. 1996, ApJ, 462, L17
Steidel, C. C., Adelberger, K. L., Giavalisco, M., Dickinson, M., & Pettini, M. 1999, ApJ, 519, 1
Yagi M. 1998, University of Tokyo Ph.D. thesis
Yoshikawa, K., Taruya, A., Jing, Y. P., & Suto, Y. 2001, accepted in ApJ, astro-ph/0104361

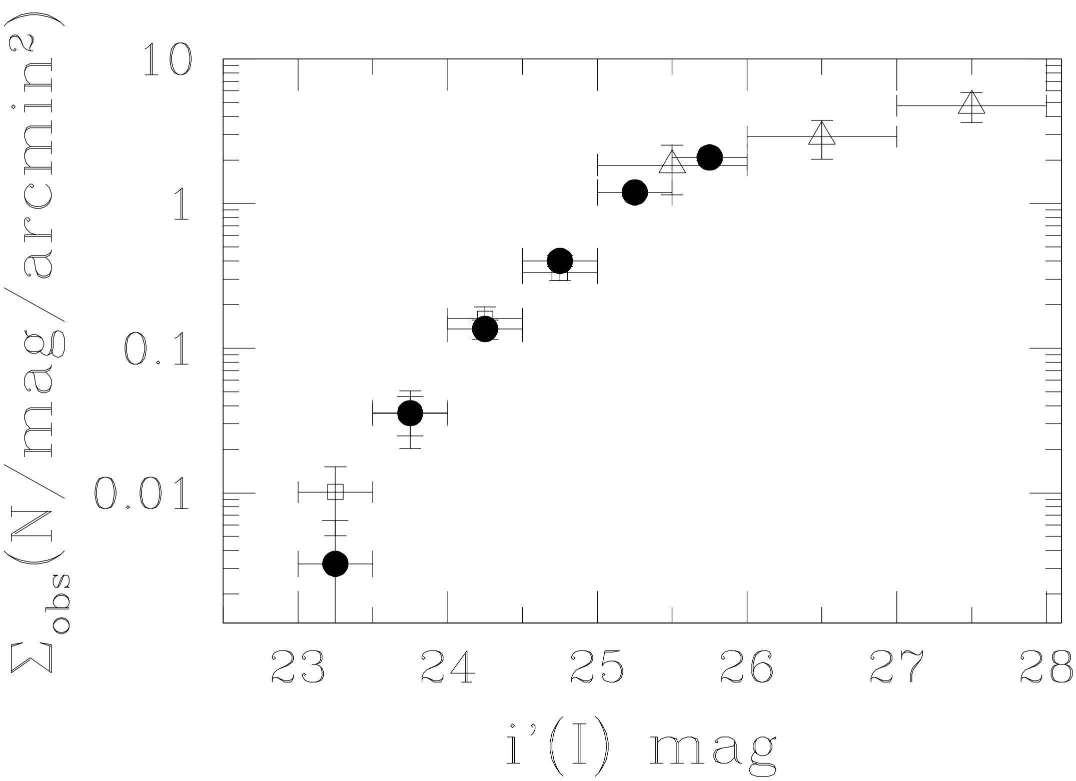

FIG. 1.— Observed surface densities of $z \sim 4$ LBGs in i' (or I) magnitude without correction for incompleteness of detections. Filled circles show our 1192 objects. Open squares are similarly color-selected objects using GRI by Steidel et al. (1999). Triangles indicate objects in the HDFN selected by us using eq.(1), whose magnitudes have been transformed to our BRi' magnitudes following Ouchi et al. (2001).

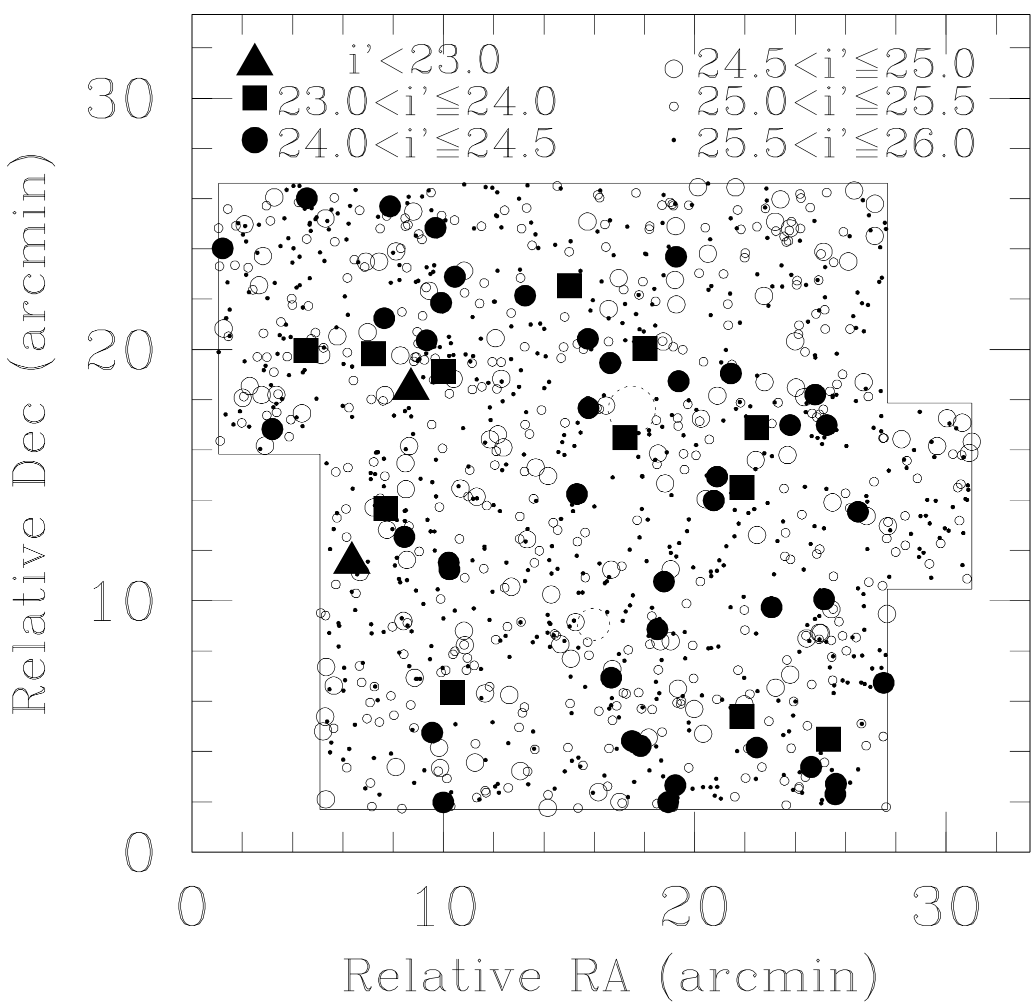

FIG. 2.— Sky distribution of our $z \sim 4$ LBG candidates. Different symbols correspond to different magnitude bins defined in the panel. Masked regions to avoid effects of bright stars are shown by dashed circles.

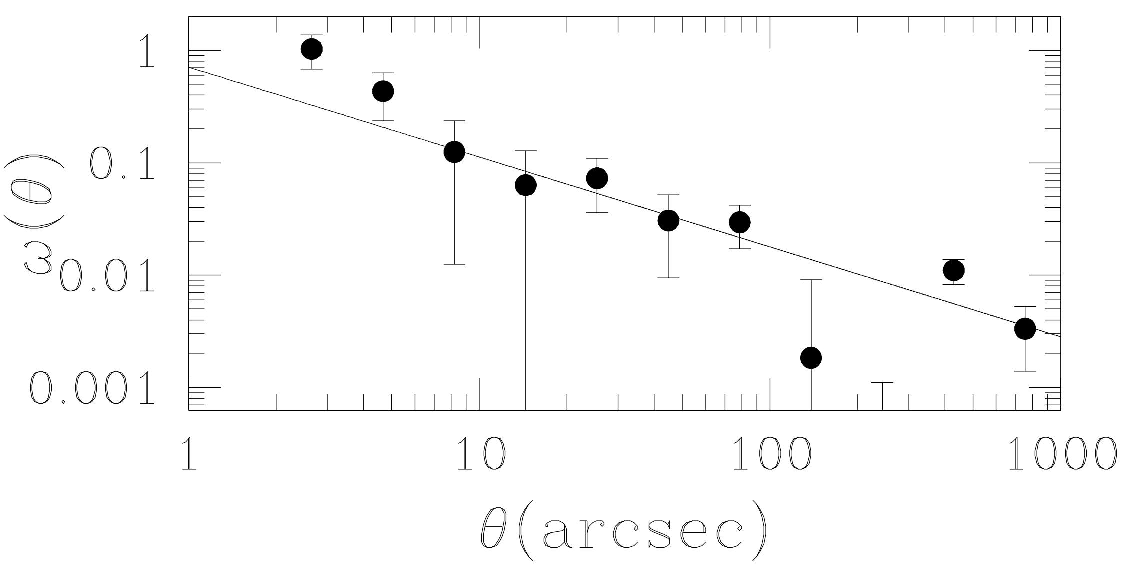

FIG. 3.— Angular correlation function for the whole sample. The solid line shows the best fit power law with $\omega(\theta) = A_\omega \theta^{-0.8}$.

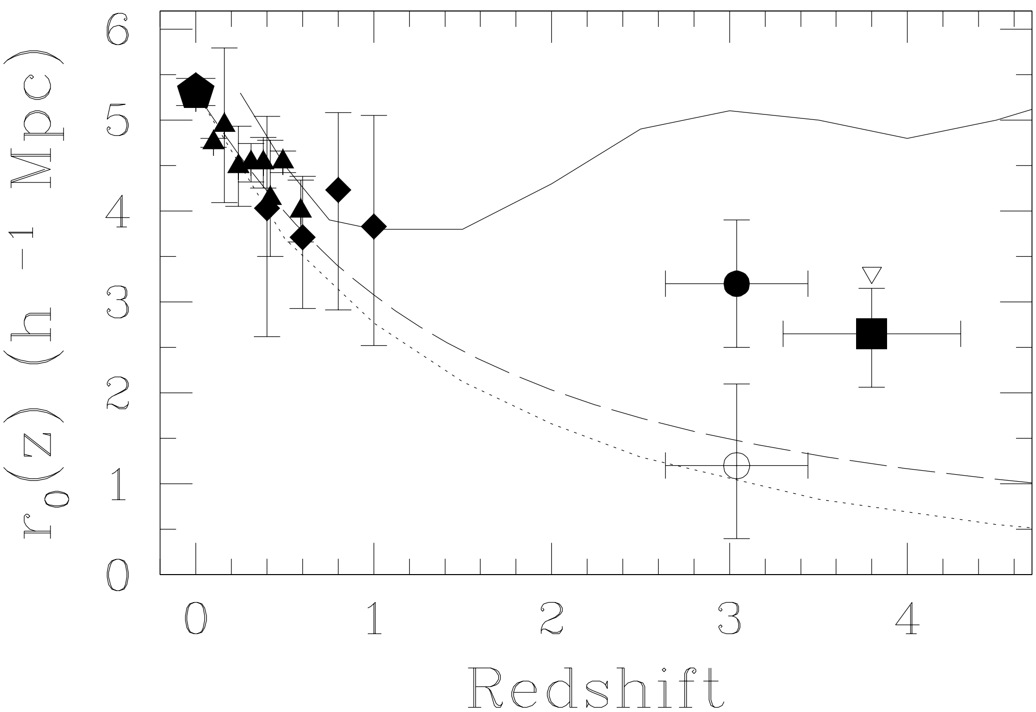

FIG. 4.— Correlation lengths at various redshifts in comoving units. The filled square indicates the value for our whole sample, while filled and open circles are those of $z \sim 3$ LBGs with $R < 25.5$ and $R < 27$ (GD01). The open inverse triangle shows the upper limit value for our whole sample, when the sample contamination maxmumly dilutes the angular correlation function. Filled pentagon, triangles, and diamonds represent measurements for nearby and intermediate-redshift bright galaxies (Loveday et al. 1995, Carlberg et al. 2000, Brunner, Szalay, & Connolly 2000). The dashed line shows the prediction of linear theory normalized to $r_0(0) = 5.3h^{-1}$ Mpc. Dotted and solid lines are r_0 of dark matter and galaxies with R <25.5 (including dust extinction) predicted by a semi-analytic model (Baugh et al. 1999).

Table 1
Sample definitions and correlation properties.

Sample	Magnitude Range	N_{obj}[a]	$\langle i' \rangle$[b]	$\langle R - i' \rangle$[c]	f[d]	A_{ω}[e]	r_0[f](Open,EdS)[h^{-1}Mpc]
whole	$i' < 26$	1192	25.5	0.12	0.165	0.71 ± 0.26	$2.7^{+0.5}_{-0.6}(2.4^{+0.5}_{-0.5}, 1.6^{+0.3}_{-0.4})$
bright	$i' < 25.5$	549	25.2	0.12	0.189	0.97 ± 0.57	$3.2^{+1.0}_{-1.2}(2.9^{+0.9}_{-1.1}, 1.9^{+0.6}_{-0.7})$
faint	$25.5 < i' < 26$	643	25.8	0.10	0.144	0.56 ± 0.25	$2.4^{+0.5}_{-0.7}(2.1^{+0.5}_{-0.6}, 1.4^{+0.3}_{-0.4})$

[a]Number of LBG candidates.

[b]Median i' magnitude of the sample.

[c]Median $R - i'$ color of the sample.

[d]Fraction of contaminant sources.

[e]Best fit amplitude of power law function for the angular correlation function. The slope of power law is $\beta = \gamma - 1 \equiv 0.8$ (fixed). The reduced χ^2 of the fitting is 2.1, 2.3, and 0.6 for the whole, bright and faint samples, respectively.

[g]Correlation length (comoving) in a Λ-dominated universe (open universe and Einstein de-Sitter universe).